Neutron activation in Ar/CO_2–filled neutron detectors

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11 September, 2018, IKON15, Lund

Outline

- ESS: brightest spallation source
- High intensity:
  - Higher signal provided
  - Higher activation
    - Nuclear waste production
    - Activity emission
    - Gamma radiation:
      background for measurement and occupational exposure

- ^{3}He replacement with B_4C-Ar/CO_2 detectors
  - New sources of activation:
    - Large volume Ar/CO_2
    - Aluminium frame

→ **Activity study needed**

Overview on Ar activation

- Ar activation is known as an issue in several areas:
  - Nuclear power plants
  - Research reactors
  - Accelerator tunnels

B. J. Jun, et al., Nuclear Engineering and Technology (2014) Vol. 42 (2).
M. Hoq, et al., Journal of Environmental Radioactivity 153 (2016) 68-72.
C. Rojas-Palma, et al., DOI: 10.1093/rpd/nch020
B. Lauritzen, et al. Int. J. of Environmental and Pollution 20 (1-6) (2013) 47-54.
https://www.cdc.gov/nceh/radiation/savannah/Chapter_04-3.pdf
https://digital.library.unt.edu/ark:/67531/metadc678287/

- Permanent activity emission during normal operation
  - Airborne radionuclides
  - ^{41}Ar main contributor:
    - thermal neutron capture in ^{40}Ar (99.3% in natural Ar)
  - Natural Ar in air or air dissolved in cooling water

Few 1000 GBq/year activity release

↓

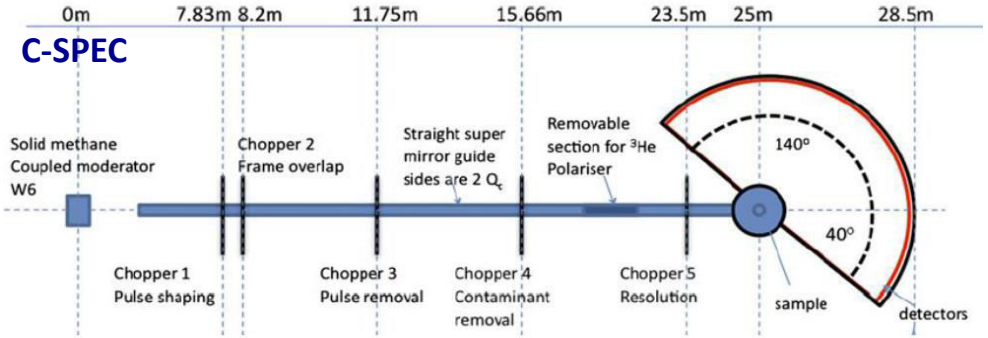
Argon in presence of neutron have to be studied for activation

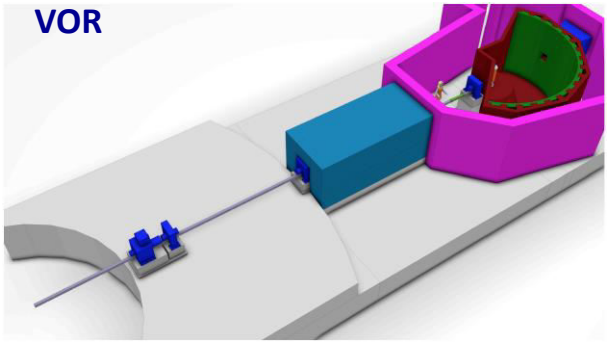
Large area detectors at ESS with Ar/CO_2

A. Khaplanov et al.
http://dx.doi.org/10.1016/j.nima.2012.12.021

- VOR, C-SPEC, T-REX @ ESS
  - Chopper spectrometers with large area detectors
  - Multi-Grid detector (*ILL/ESS/LU collaboration*): $^{10}B_4C$ converter based detector with Ar/CO_2
  - Continuous counting gas flow

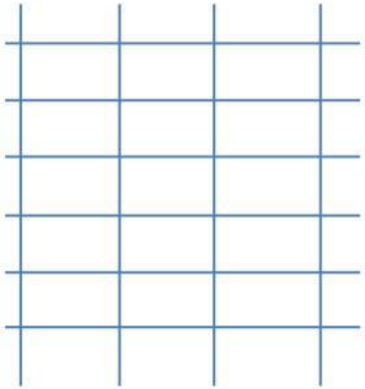
Large Ar/CO_2 counting gas volumes exposed to neutron radiation (V~5-10 m^3)





Neutron activation study

- Neutron induced gamma background:
  - Prompt gamma
  - Decay gamma
- Activity production



- Activation study:
  - General Ar/CO_2 detector
  - Standard ESS operational conditions
  - MCNP6.1 simulation
    - Prompt gamma spectrum
    - Decay gamma calculation with Table of Isotopes
  - Analytical calculation:
    - Prompt: IAEA PGAA Database
    - Decay gamma calculation with Table of Isotopes

Table of Isotopes: http://nucleardata.nuclear.lu.se/toi/
IAEA Prompt Gamma Activation Analysis Database: https://www-nds.iaea.org/pgaa/

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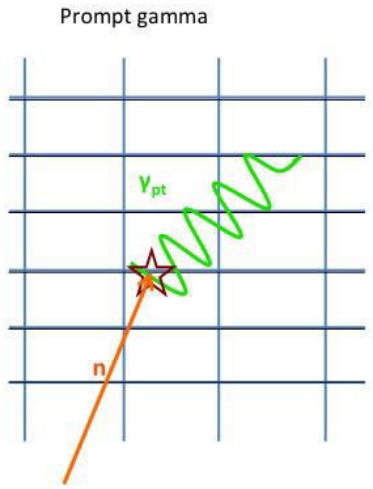

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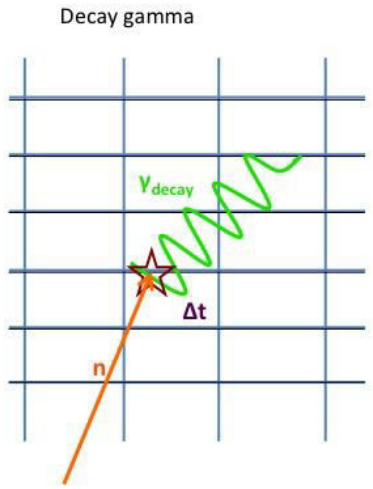

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Cross section libraries

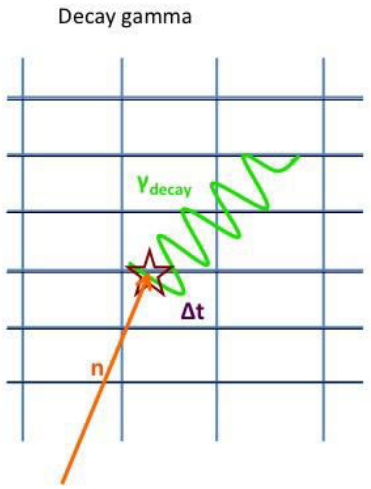

Table of Isotopes: http://nucleardata.nuclear.lu.se/toi/
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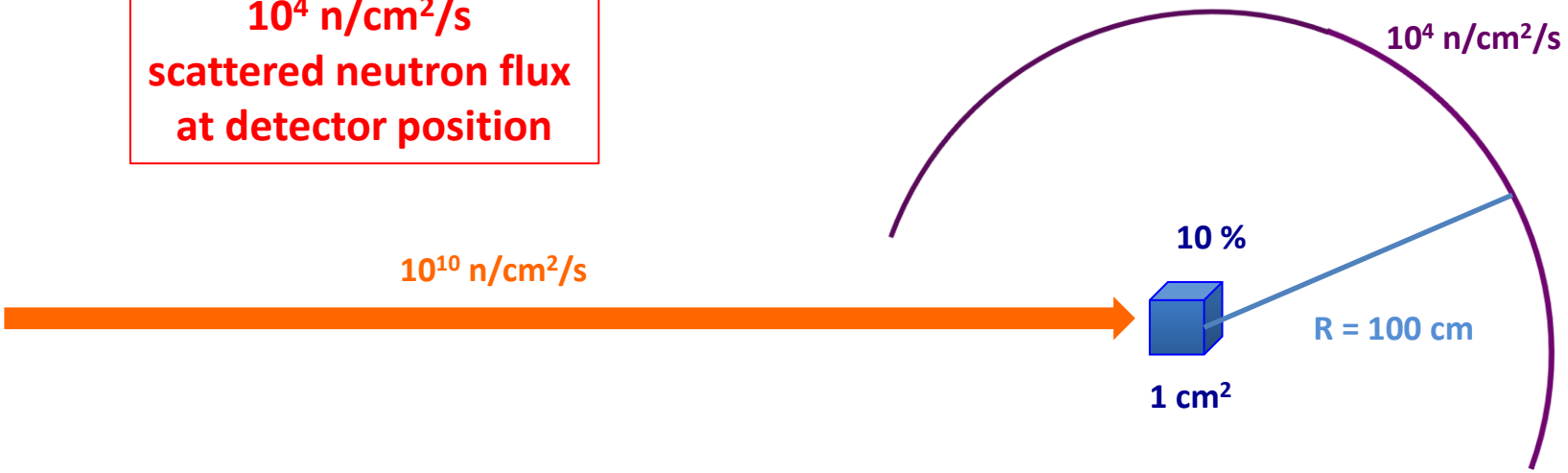
Assumptions and conditions

Standard operational conditions for ESS

- Estimation of irradiating neutron flux
  - Various fluxes at sample position (VOR, T-REX, C-SPEC): conservative estimation: 10^{10} n/cm^2/s
  - 1-10 % scattering on sample
  - 1 cm^2 sample surface

  → 10^9 n/s scattered neutron
  - R = 100 cm smallest realistic sample-detector distance → 10^5 cm^2 sphere surface

10^4 n/cm^2/s scattered neutron flux at detector position

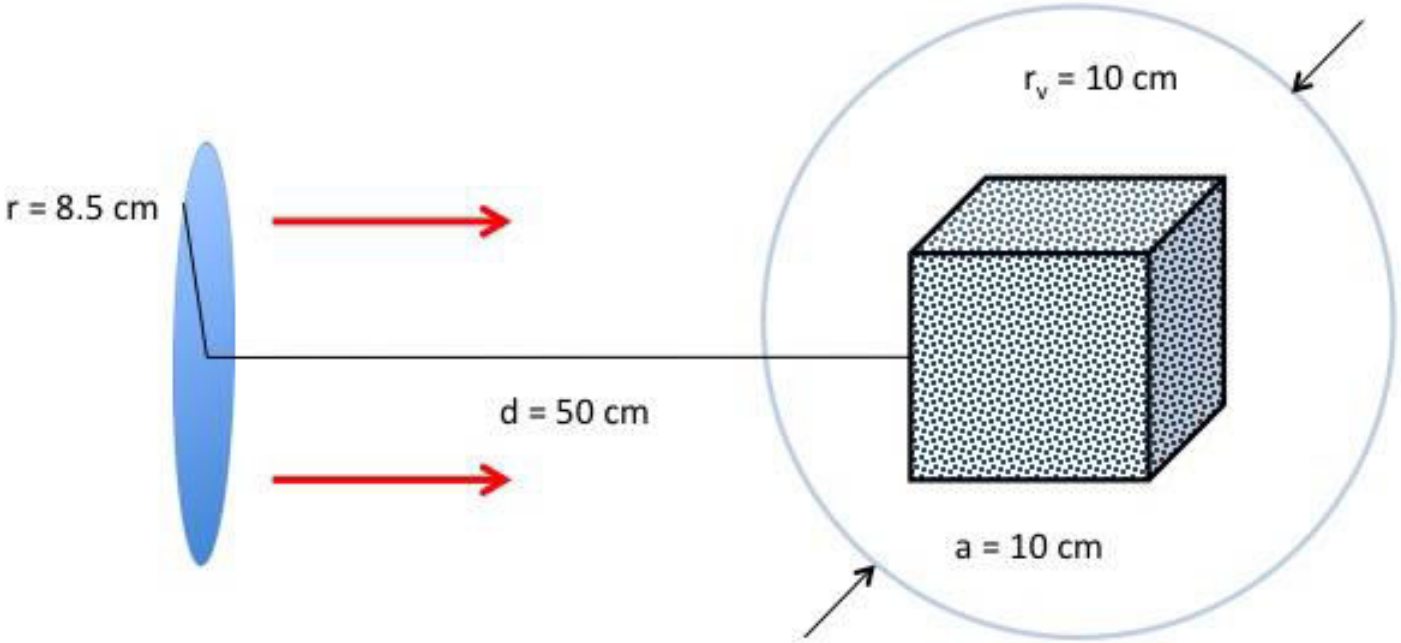


Assumptions and conditions

- Ar/CO_2 detector model for simulation and calculation:
  - 10 x 10 x 10 cm^3 gas cube
  - 5 mm thick aluminium frame, Al5754 alloy
  - r = 8.5 cm mono-energetic pencil beam
    - 0.6, 1, 1.8, 2, 4, 5, 10 Å

- $t_{irr} = 10^6$ s irradiation time
  (typical spallation source operation cycle)
- $t_{cool} = 10^7$ s cooling/decay time

Assumptions and conditions



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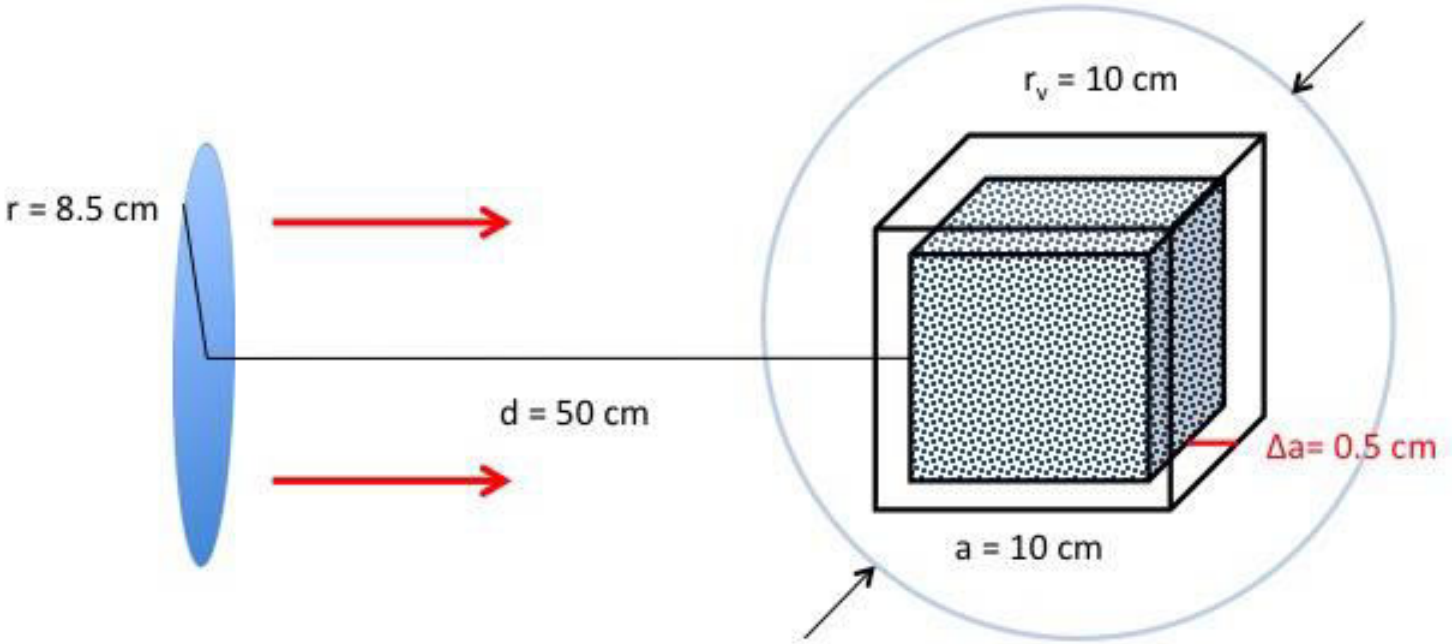

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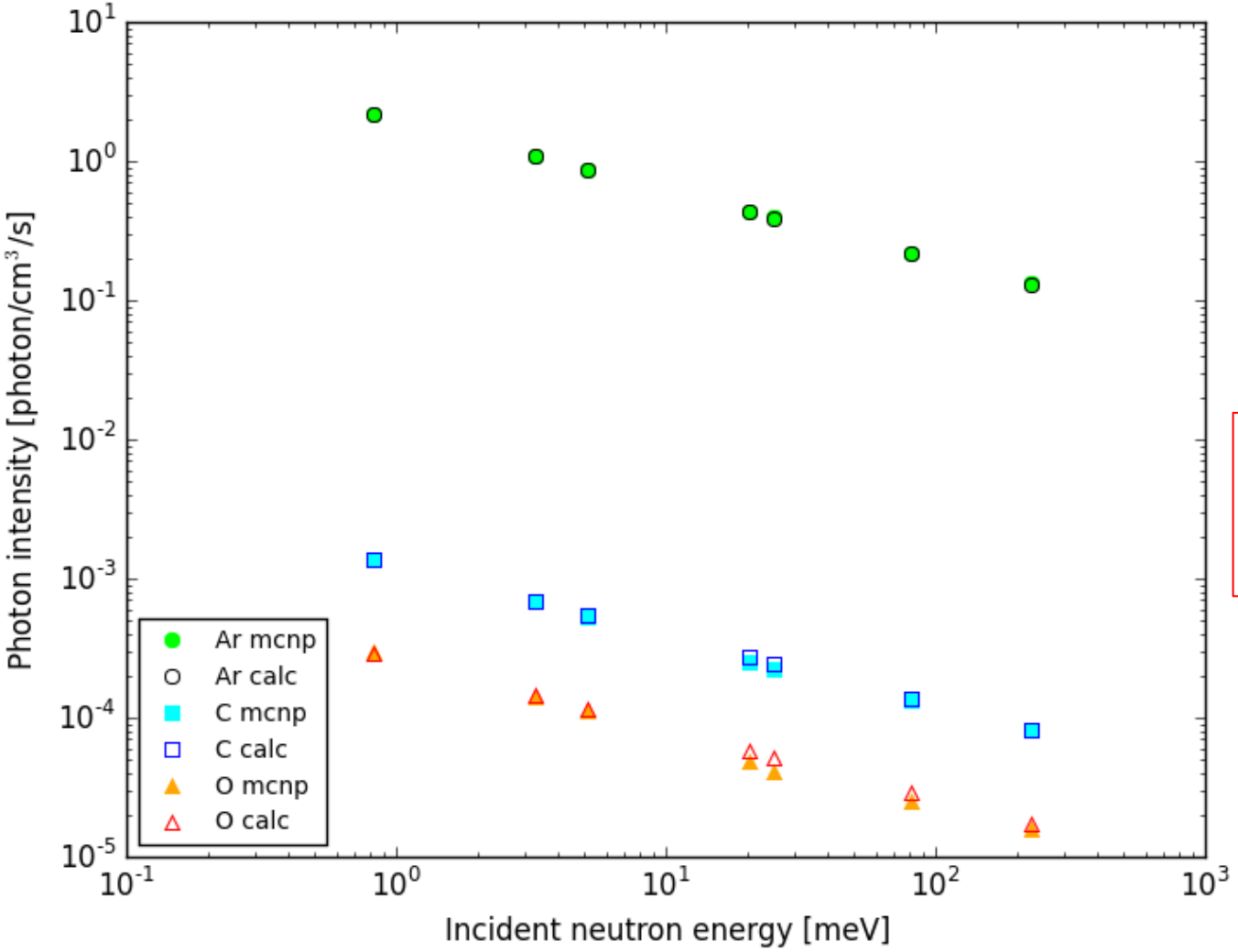
Calculated and simulated prompt and decay gamma spectra and activity

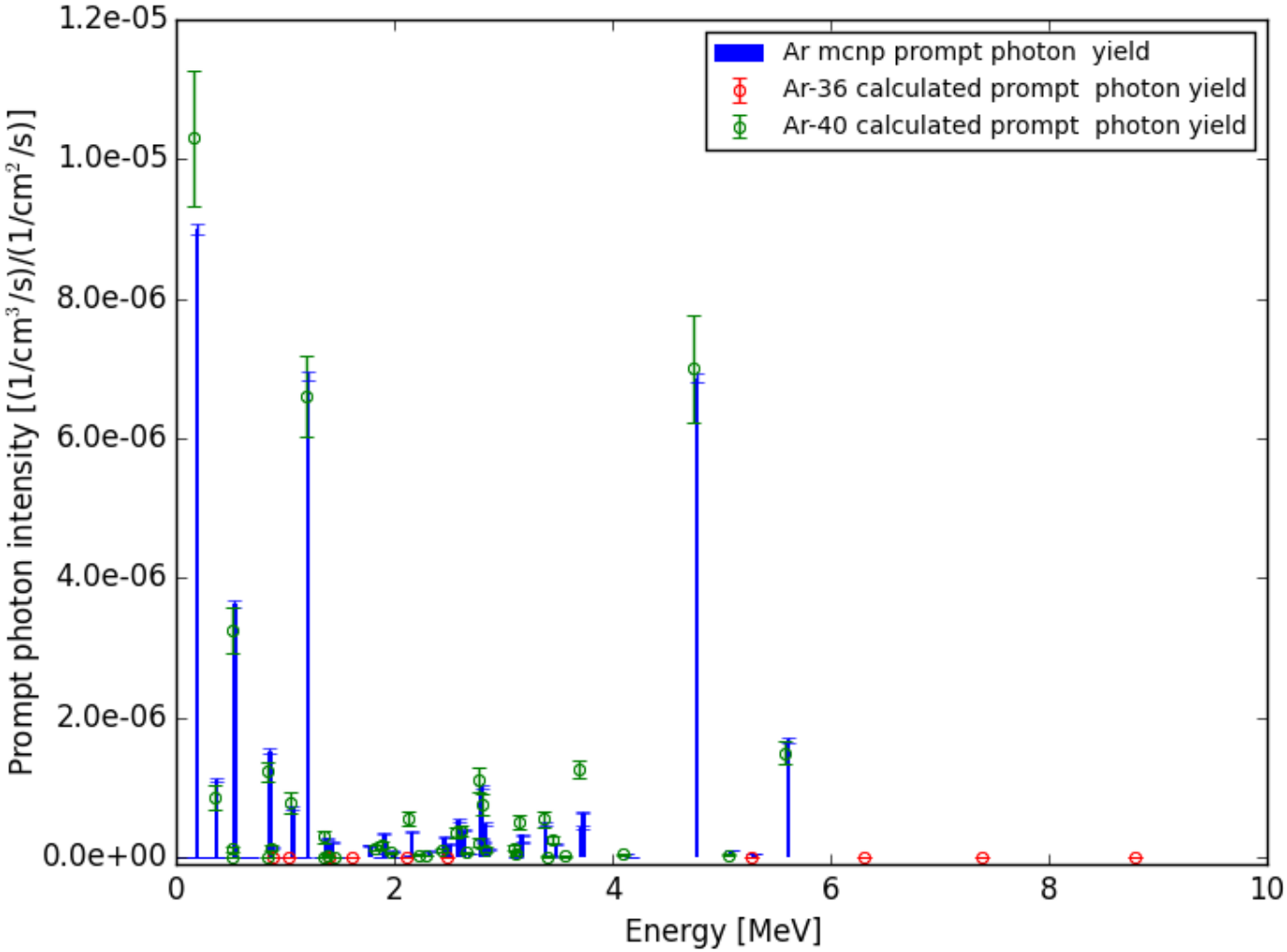
Calculated and simulated prompt photon intensity in Ar/CO_2



Agreement between calculated and simulated photon yield

With the proper databases, analytical calculations can be replaced with MCNP simulation

Calculated and simulated prompt photon spectra in Ar

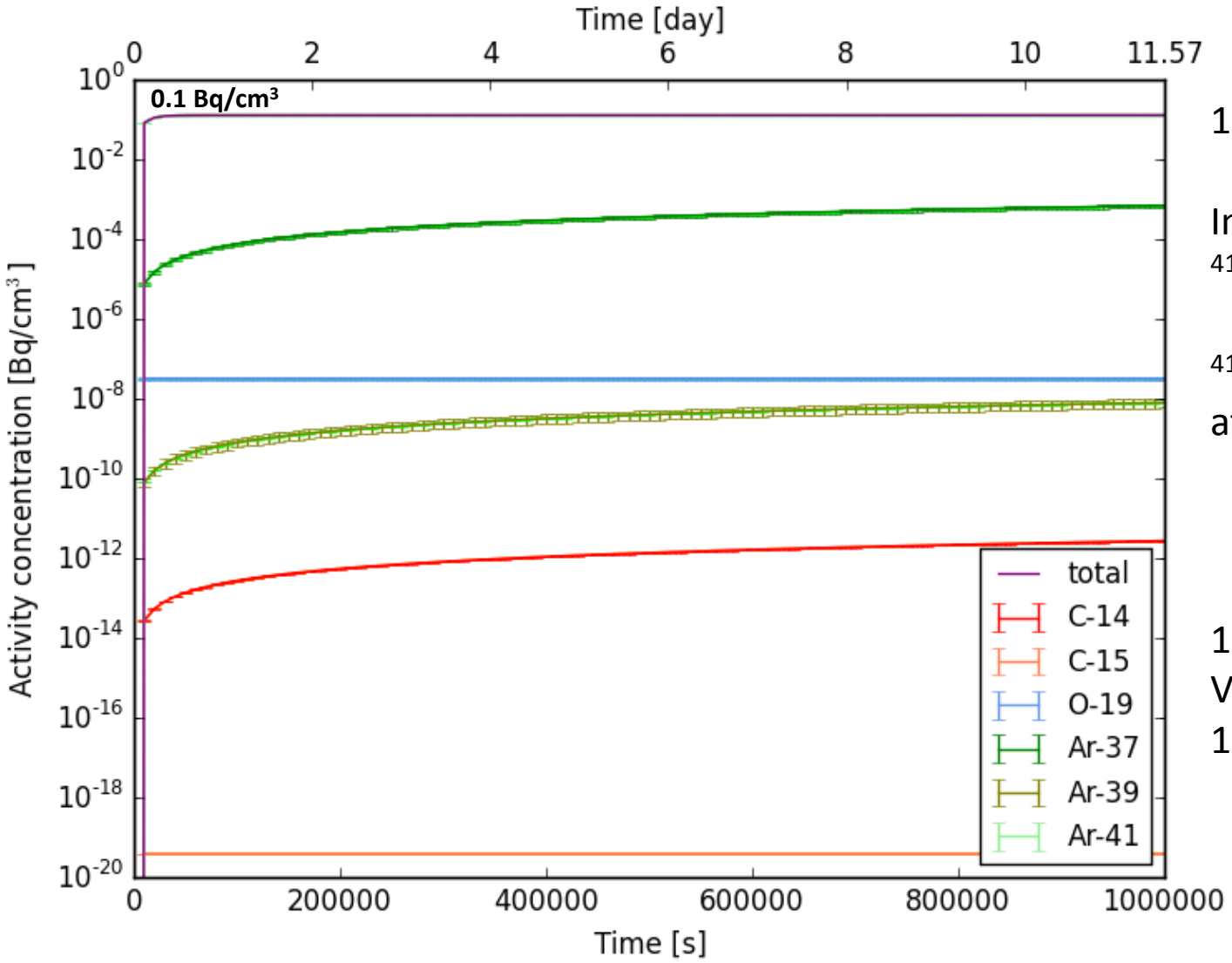


1.8 Å, normalised to incident flux

Agreement between calculated and simulated spectra

With the proper databases, analytical calculations can be replaced with MCNP simulation

Activity build up in Ar/CO_2



1.8 Å

Instant
^{41}Ar background

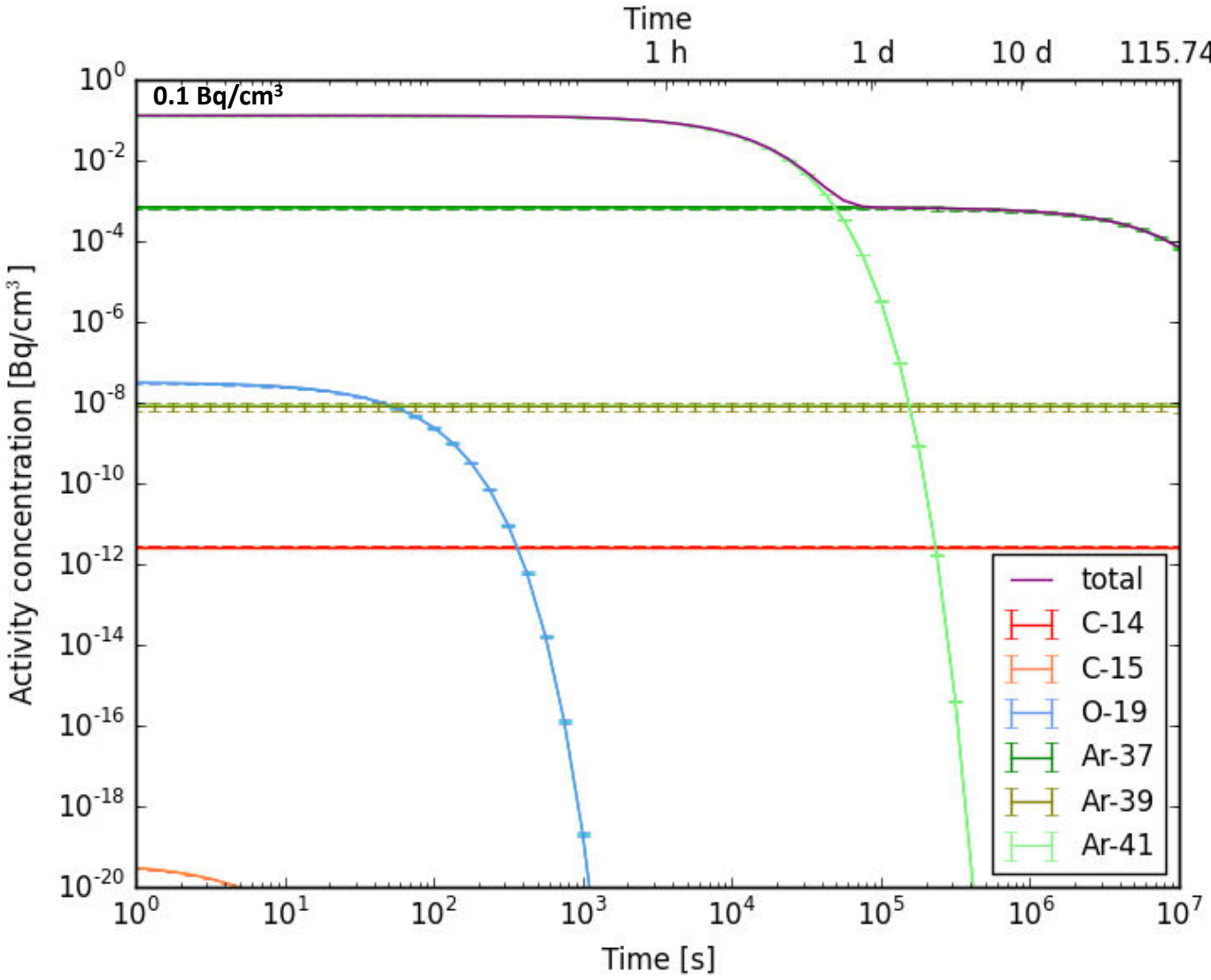
^{41}Ar activity saturates at **128 mBq/cm³**

↓

low

1 detector volume/day:
V ~ 10 m^3
1.28 x 10^6 Bq/day

Activity decay in Ar/CO_2



1.8 Å

Instant
^{41}Ar background

^{41}Ar activity saturates at **128 mBq/cm³**

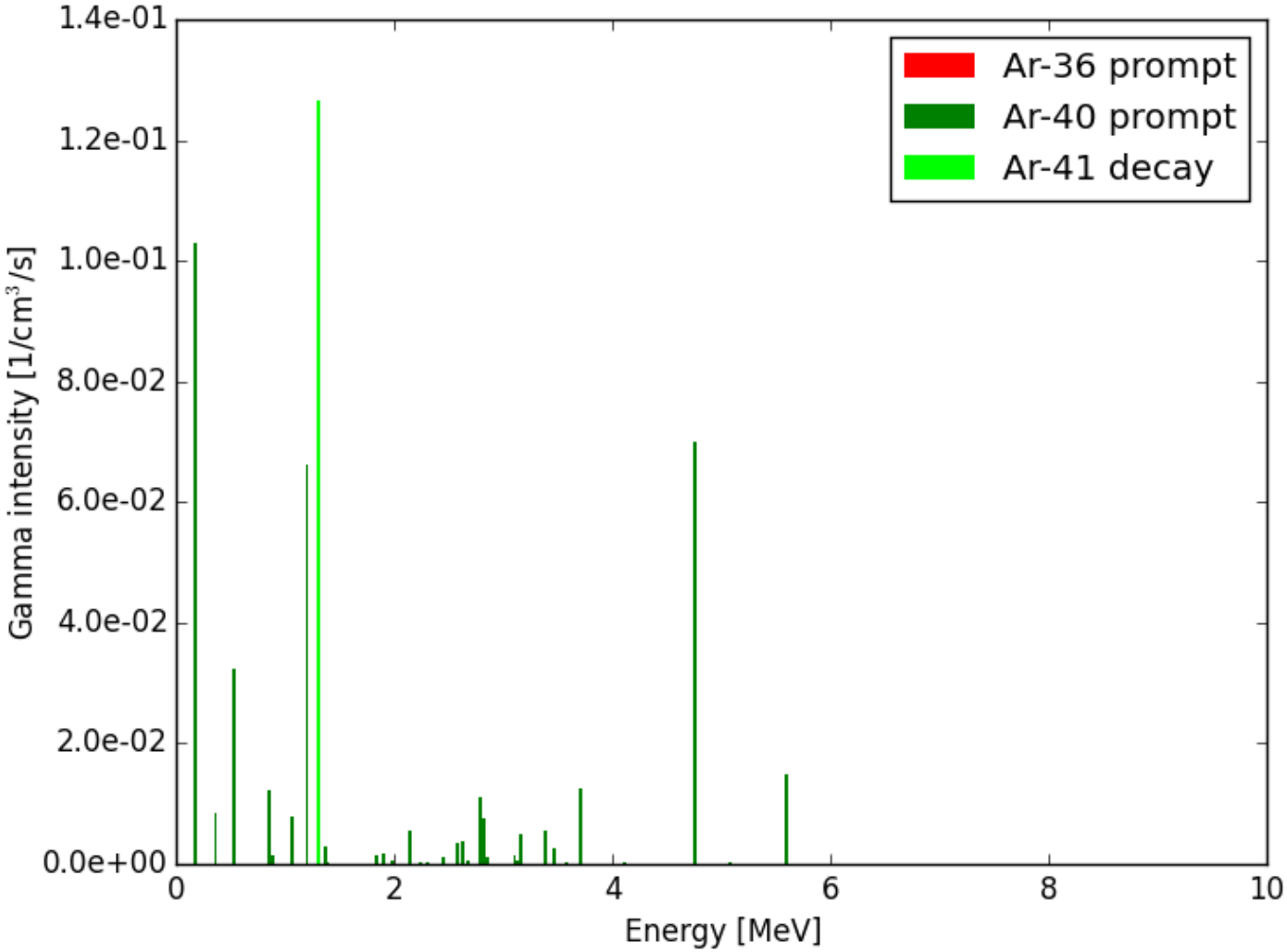
↓

low

1 detector volume/day:
V ~ 10 m³
1.28 x 10^6 Bq/day

Negligible emission with 1 day cooling

Calculated prompt and decay photon spectrum in Ar

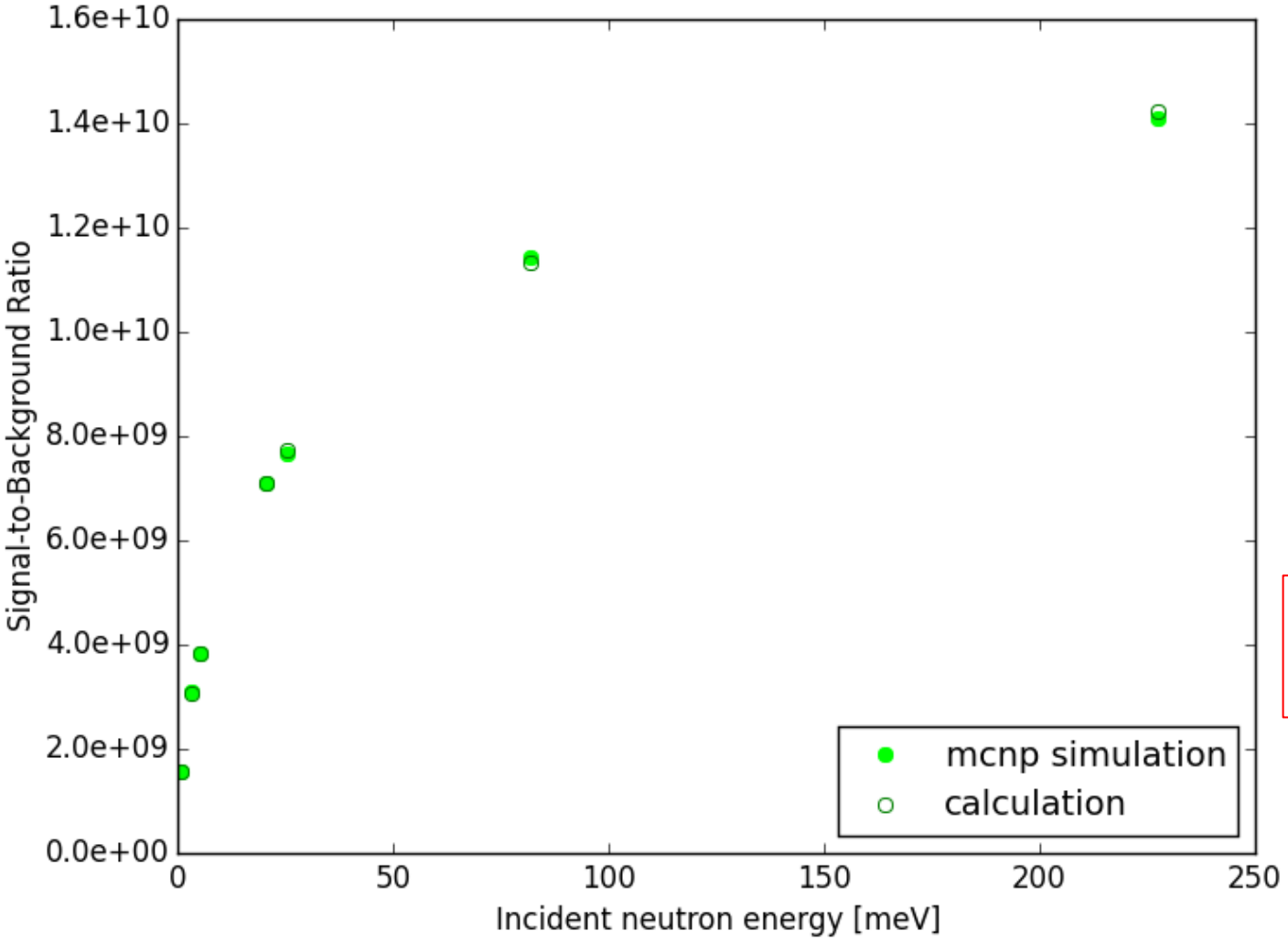


1.8 Å

Comparable prompt and decay gamma yield

Considerable decay gamma background during operation

Signal-to-(neutron-induced gamma background) Ratio



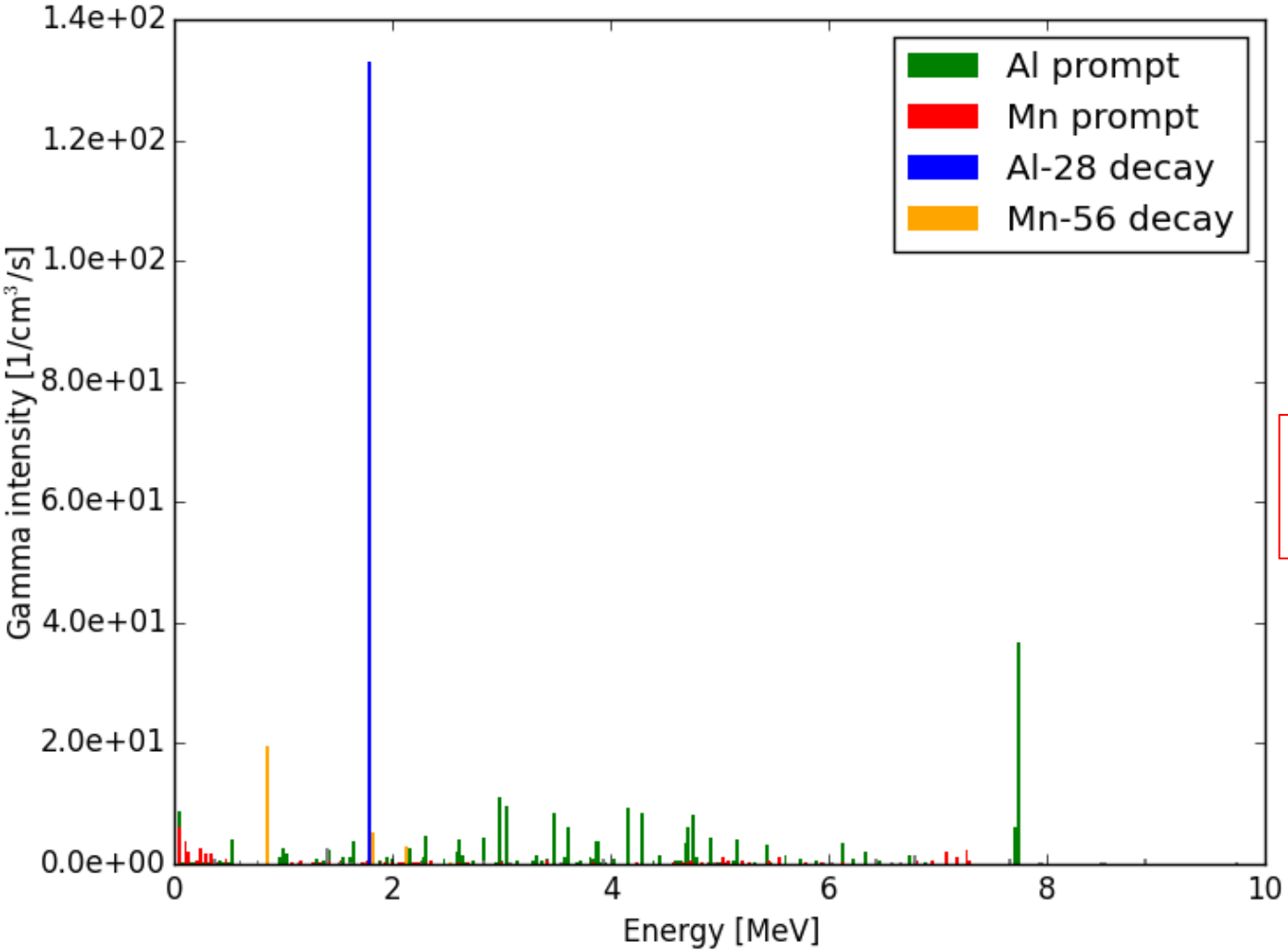
Multi-Grid detector as an example

SBR changes between 10^{9}-10^{10} for the whole energy range

The gamma background is negligible even for beam monitors (10^{-5} efficiency)

The gamma background is negligible in terms of the measured signal

Calculated prompt and decay photon spectrum in Al5754

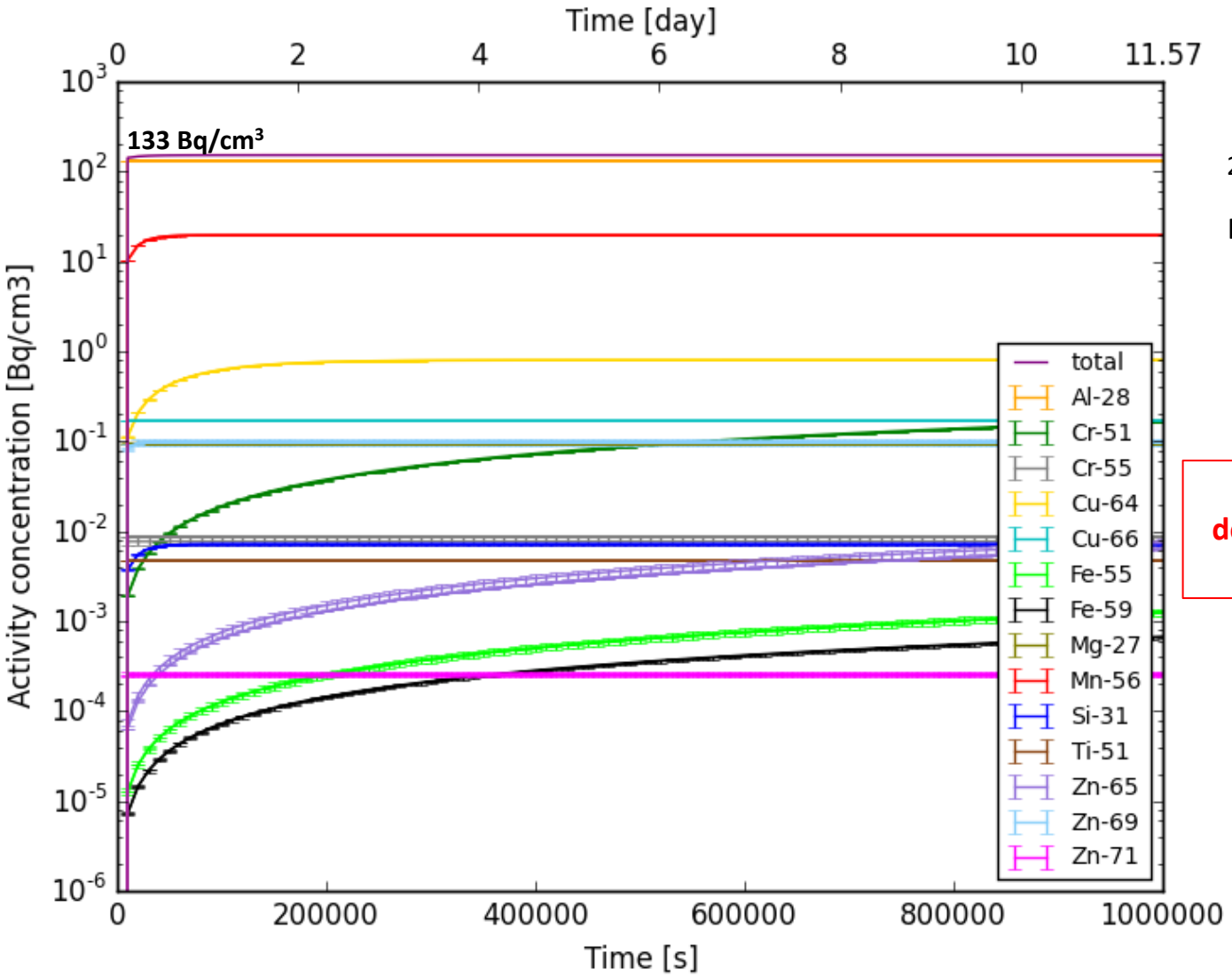


1.8 Å

Comparable prompt and decay gamma yield, mainly given by **Al** and **Mn**

Considerable decay gamma background during operation

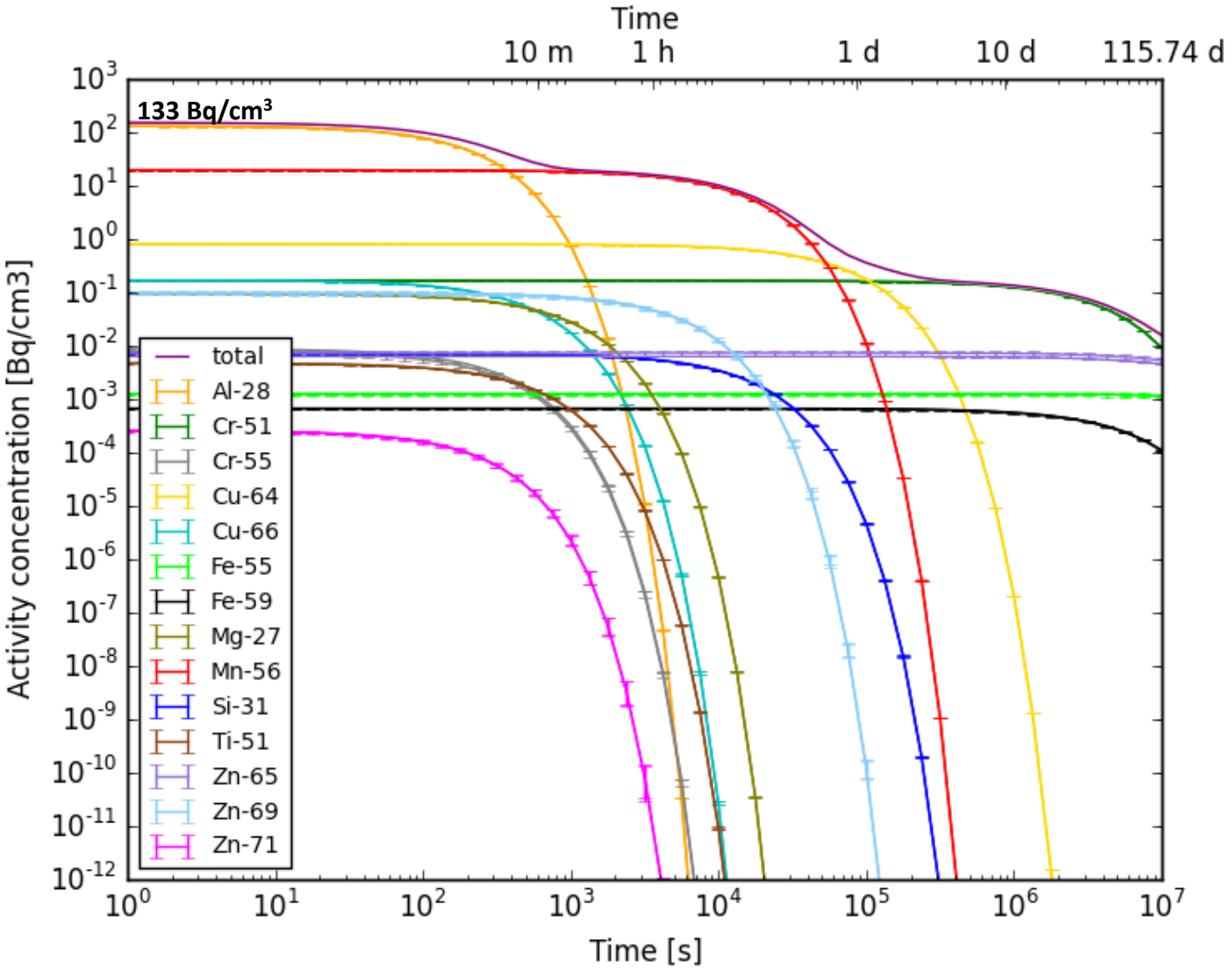
Activity build up in Al5754



^{28}Al and ^{56}Mn main contributors

Considerable decay gamma background during operation

Activity decay in Al5754



1/1000 activity
with 1 day cooling

Applied Radiation and Isotopes 128 (2017) 275–286

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Neutron activation and prompt gamma intensity in Ar/CO_2-filled neutron detectors at the European Spallation Source

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E. Dian et al.
10.1016/j.apradiso.2017.06.003

HIGHLIGHTS

- Effect of neutron activation on argon based detector counting gas studied.
- Dataset collected for neutron activation and prompt gamma production MCNP simulation.
- Generally applicable activity and prompt photon emission data is given.
- The activity emission from the studied continuous flow detectors is negligible.
- The increase of background from neutron induced gamma radiation is negligible.

ARTICLE INFO

Keywords:
ESS
Neutron detector
B4C
Neutron activation
^{41}Ar
MCNP
Monte Carlo simulation

ABSTRACT

Monte Carlo simulations using MCNP6.1 were performed to study the effect of neutron activation in Ar/CO_2 neutron detector counting gas. A general MCNP model was built and validated with simple analytical calculations. Simulations and calculations agree that only the ^{40}Ar activation can have a considerable effect. It was shown that neither the prompt gamma intensity from the ^{40}Ar neutron capture nor the produced ^{41}Ar activity have an impact in terms of gamma dose rate around the detector and background level.

1. Introduction

Ar/CO_2 is a widely applied detector counting gas, with long history in radiation detection. Nowadays, the application of Ar/CO_2-filled detectors is extended in the field of neutron detection as well. However, the exposure of Ar/CO_2 counting gas to neutron radiation carries the risk of neutron activation. Therefore, detailed consideration of the effect and amount of neutron induced radiation in the Ar/CO_2 counting gas is a key issue, especially for large volume detectors.

In this paper methodology and results of detailed analytical calculations and Monte Carlo simulations of prompt and decay gamma production in boron-carbide-based neutron detectors filled with Ar/CO_2 counting gas are presented (see Appendix).

In Section 3 a detailed calculations method for prompt gamma and activity production and signal-to-background ratio is introduced, as well as a model built in MCNP6.1 for the same purposes. The collected bibliographical data (cross section, decay constant) and the cross section libraries used for MCNP6.1 simulation are also presented.

In Section 4 the results of the analytical calculations and the simulation, their comparison and their detailed analysis are given.

In Section 5 the obtained results are concluded from the aspects of gamma emission during and after irradiation, radioactive waste production and emission, and the effect of self-induced gamma background on the measured signal.

2. Context

The European Spallation Source (ESS) has the goal to be the world's leading neutron source for the study of materials by the second quarter of this century (European Spallation Source ESS ERIC; ESS Technical Design Report, 2014). Large scale material-testing instruments, beyond the limits of the current state-of-the-art instruments are going to be served by the

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http://dx.doi.org/10.1016/j.apradiso.2017.06.003
Received 30 January 2017; Received in revised form 3 June 2017; Accepted 5 June 2017
Available online 07 June 2017

Summary

- Ar and aluminium activation can be an issue for neutron detectors, neutron activation has to be considered
- Simple and general MCNP6.1 model built for activation study
  - Proper cross section databases found
  - Analytical calculations can be replaced by simulation

Neutron induced gamma signal is negligible in terms of SBR

Negligible activity emission from continuous gas flow with 1 day storage

Prompt and decay gamma yields and activity are determined for the whole energy range and available in an easy-to-scale form

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Thank you for your attention!